BOONTON ELECTRONICS
CORPORATION
PARSIPPANY, NEW JERSEY U.S.A.

TRLR

ADDENDUM FOR 35A

INSTRUCTION MANUAL

SID-544368-A1

The calibration of the Model 35A Q-Bridge is a complex procedure. It should not undertaken without a knowledge of the theory of the instrument, and some experience in the field of rf measurements.

Although the theory of operation of the Model 35A is described in the Instruction Manual, a few additional explanatory remarks should be made with regard to the bridge section. It consists of the usual four bridge arms, each with a capacitor; one of them variable. An internal standard capacitor is substituted for the test specimen during the initial balance of the bridge. Balance is achieved by adjusting the variable capacitor to equalize the products of the capacitances in opposite bridge arms, and adjusting the loss so that it is properly distributed.

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To make the operation of the instrument feasible, certain design parameters were incorporated. They are:

1. The use of ratio capacitors which:

a) permits the use of a low-capacitance standard for the measurement of relatively large values of C_x. This sensibly eliminates the effect of series inductance in the standard capacitor at the higher operating frequencies. The three-terminal construction of this capacitor also confines the loss to series resistance with its attendant skin effect, except at the low capacitance end of the range which will be discussed later.

b) reduces the test level for C_x which is desirable for the measurement of semiconductors.

c) holds the low test-terminal at a low impedance level.

2. A quasi three-terminal measuring circuit allows compensation with either positive or negative conductance.

3. A special output transformer generates a compensating voltage for the series inductance and resistance of the test arm of the bridge.

The principal sources of error in the Model 35A for the measurement of Q, are:

1. Calibration of the tuned voltmeter/detector.

2. Residual resistance of the test terminals and test arm of the bridge, and variable loss in the standard capacitor at the low-capacitance end of its range.

3. Initial adjustment for balance of bridge loss.

These, and other adjustments and calibration procedures, not covered fully in the 35A Instruction Manual, will be described in this addendum.

The complete calibration of the 35A Q-Bridge involves adjustments in a number of sections in the instrument, which are categorized as follows:

1. Calibration of the tuned voltmeter/detector
2. Calibration of the variable standard capacitor
3. Preliminary bridge adjustments
4. Compensation to permit capacitor stacking
5. Compensation for proper Q balance

Tuned Voltmeter/Detector

The procedure as given in the Model 35A Instruction Manual, Revised Copy - 3/77, is complete and satisfactory for this part of the calibration.

Variable Standard Capacitor

Under normal circumstances the variable standard capacitor should not require recalibration. It should be noted that the principal function of this instrument is for the measurement of the Q-factor of capacitors, and not the capacitance. The measured capacitance should not be grossly in error, of course, but we must caution against an unnecessary recalibration to correct minor faults that will be costly, and may, indeed, worsen the calibration.

If it becomes necessary to recalibrate the variable standard capacitor, the bridge section should be removed from the instrument and mounted in a swivel fixture so that the dial and the capacitor plates are readily accessible for viewing and adjustment.

A number of standard capacitors will be needed for the test terminals. For convenience, they can be mounted in a shielded box and switched, but the stray capacitance to the case (ground) must be kept small or it will affect the capacitance ratio of the bridge. The Boonton Model 76-3A Precision Decade Capacitor will provide all the values needed for recalibration, but it should be adapted for connection to the 35A test terminals with the left terminal of the 76-3A on the LO post. With this connection the ratio of the bridge arms will be increased about 1%, and the dial setting of the 35A should be 1% less than the standard value selected for the test terminals.

A generator and tuned detector should be connected to the input and output of the bridge section. External equipment may be used, but it may be more convenient to extend the coaxial cables of the instrument to the area of the bridge for this purpose. A suitable frequency for the recalibration of the variable standard capacitor is 1 MHz, especially if the Model 76-3A is used.

The lowest calibrated reading for the capacitor is 20.0 pF. This reading should coincide with the position of the rotor plates at the point of meshing with the stator plates. After establishing and adjusting this value, a large capacitance should be connected to the test terminals, i.e., 800 to 900 pF, and the ratio of the bridge can be adjusted with C-211 (Figure on page 24) to obtain the proper reading.

In the process of adjusting the end plates of the variable capacitor, it will be necessary from time to time to check the ratio because the total accumulated capacitance will change.

The most difficult region of recalibration is between 20 and 100 pF. At 20 pF, the plates should be on the verge of meshing. The adjustment at this point is the spacing of the baffle plates, which are at ground potential, and the copper strips that are at right angles to, and on the tips of the rotor plates. The capacitance of these baffle plates to the rotors is shown schematically in Figure 1. The effective capacitance for the first few degrees of rotation is largely controlled by this capacitance to ground. A close approximation to the manner in which the various capacitances change with rotation of the rotor plates is shown in Figure 2.

If backlash develops, the bearing opposite the insulated gear should be adjusted carefully, and relocked.

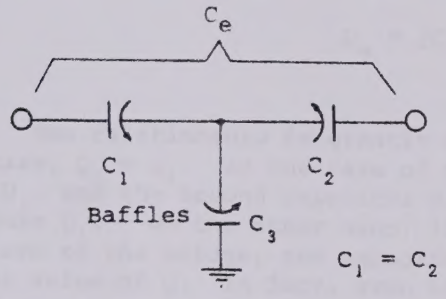

Figure 1.

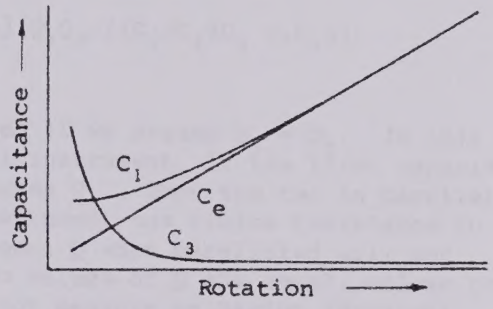

Figure 2.

Preliminary Bridge Adjustments

If there is doubt as to the accuracy of the internal 20 pF standard capacitor, an external capacitor of 20.0 pF can be connected to the test terminals. At a frequency of 1 MHz, the capacitance dial reading at balance should be noted. This reading should be 20.0 pF, ±0.4 pF. If, when the external capacitor is removed and the internal 20 pF STD capacitor is engaged, balance does not occur (very nearly), the plate of the internal capacitor should be adjusted until agreement for balance is reached with the capacitance dial set at the value noted earlier and with the 20 pF STD capacitor engaged. Access to the internal 20 pF capacitor is gained by removing the test terminals and the bridge cover-plate. This capacitor is formed by a combination of two silver-plated brass plates and the block that supports the LO post. Adjustment should be made on the outside plate.

A check should be made at several frequencies on each frequency band to determine if the range of Q balance control is sufficient to permit a Q balance over the full frequency span of the instrument. If a balance problem exists, it will most likely occur on the highest frequency band. An adjustment of C-214 should give the needed Q balance range. This capacitor is located adjacent to the GND post, and of the two capacitors at that location it is farthest from the front panel (See page 24). The adjustment has its maximum effectiveness at 50 MHz.

C-214, in conjunction with a series resistor, provides an adjustable rf conductance across the smaller ratio capacitor. The conductance developed by this network is proportional to the square of the frequency, thus its influence is diminished as the frequency is reduced. The theory of this circuit is explained fully in Boonton's Applications Note # 15 "Equivalency of RC and RL Networks".

Another adjustable conductance is provided at all frequencies by vary-

ing the bias through diodes CR-201 to CR-206, in both switched steps and with a 10 turn potentiometer (Q-BAL, COARSE & FINE). The conductance of these diodes appears across the larger of the two ratio capacitors.

Compensation for Stacking Capacitors

The most tedious operation in the 35A calibration procedure is the adjustment of compensating networks for the proper stacking of capacitors. First we must define what we mean by stacking. Assume we have a perfect instrument for the measurement of the Q-factors of capacitors. If we measure the Q-factor of a capacitor, and then parallel the terminals with a second capacitor, the instrument will measure the total effective Q-factor according to the relationship,

$$Q_e = [C_1/C_2 + 1][Q_1Q_2/\{(C_1/C_2)Q_2 + Q_1\}]$$

The relationship is greatly simplified if we assume $Q_1 = Q_2$. In this special case, $Q_e = Q_1$. In the case of the ideal instrument, if the first capacitor measures Q_1, and the second capacitor also measures Q_1, then the two in parallel will measure Q_1. On the other hand, if our instrument has finite resistance in the test arm of the bridge, two capacitors of equal Q when paralleled will not yield that value of Q. In fact, even if the two values of Q are equal, unless the values of capacitance are also equal they will not measure as having identical Q-factors. We have, therefore, a simple test for the existance of resistance in the test terminals and the test arm of the bridge, or to be correct we should say, the lack of proper compensation for these resistances, for they cannot be removed. This is the technique that we call stacking.

To substantiate the theory, let two identical capacitors of capacitance C_1, and resistance r_1 be individually connected to a Q-Bridge having a series test terminal resistance of r_0. The individual Q-factors will measure $1/\omega C_1(r_1 + r_0)$. When the two capacitors are connected in parallel to the test terminals, the Q-factor will measure $1/2\omega C_1[(r_1/2) + r_0]$. The single and combined Q-factors can be equal only if $r_0 = 0$.

At this point it should be emphasized that in actual practice it is essential that only capacitors of equal capacitance be used for stacking. We will show later that part of the stacking error between 20 and 50 pF can be the result of loss in the variable standard capacitor that changes with the position of the rotor. It is evident that unless this capacitor remains fixed for the measurement of Q of both stacking capacitors, the Q values may be affected by the movement of the variable capacitor. It is convenient if the two Q-factors of the stacking capacitors are also equal, but if they are not, the relationship is simply,

$$1/Q_e = 1/Q_1 + 1/Q_2$$

One additional note is worth mention. When testing an instrument for its ability to properly stack two capacitors, it is not necessary to have the bridge properly balanced for Q. In fact, in order to achieve maximum resolution for the measurement of Q without the annoying effect of noise which obtains near Q balance ($Q > 5000$), we recommend that the Q balance controls be adjusted so that the individual Q-factors equal about 2000. The combined Q, of course, should also equal 2000. Once the bridge is properly compensated so that it stacks correctly, a few simple tests will show that stacking is independent of the initial setting of the Q balance controls, even to the extent of stacking for negative values of Q. Negative Q readings occur when the Q balance controls are turned clockwise through

the balance point and readings again obtain on scale. When starting the compensating adjustments for stacking, it is important that the initial Q readings be for positive Q values, otherwise the rules which are given later for the adjustments of these networks will be void.

When the bridge is improperly compensated, capacitors will stack either high or low. By this, we mean the combined Q will be either higher or lower than the individual Q value, or higher or lower than $1/Q_1 + 1/Q_2$. If the bridge stacks high, it may extend to the negative Q region. For this reason, when stacking we recommend that the polarity of the measured Q values constantly be checked. The test is simple. The indicated value of Q is positive if a clockwise rotation of the FINE Q balance control increases the reading.

Compensation for the stacking of capacitors must be applied to the bridge in two areas; a) the output transformer phase, which accounts for the series resistance in the test arm and terminals, and b) the loss in the variable standard capacitor, which changes sufficiently between 20 and 50 pF to warrant compensation. Above approximately 50 pF the loss is sensibly constant. We will consider these two conditions separately.

Series resistance in the test arm: A brief analysis of the voltage derived from the output transformer will show the advantages which obtain from this element.

The bridge circuit and output transformer are shown in Figure 8 in the Instruction Manual. To make the analysis manageable, the following constraints are placed on the circuit.

1. The total inductance of the test arm is lumped into L_1.
2. The Q-factor of C_x is infinite.
3. For the first part of the analysis, assume that $Z_A = 0$, and $Z_B = \infty$.

From the circuit of Figure 8,

$$e_3 = e_1 - e_2 \tag{1}$$

$$e_o = e_3 - e' = e_1 - e_2 - e' \tag{2}$$

and,

$$i_1 = e_g \omega C [n/(1 + n)] \tag{3}$$

thus,

$$e_1 = i_1/n\omega C = e_g/(1 + n) \tag{4}$$

Also,

$$i_2 = e_g/(r + r_s - j/\omega C_x - jn/\omega C_x + j\omega L_1) \quad * \tag{5}$$

and,

$$e_2 = \frac{r - j/\omega C_x + j\omega L_1}{r_t - j(1 + n)/\omega C_x + j\omega L_1} \qquad (r_t = r + r_s^*) \tag{6}$$

Expanding and simplifying, [$(\omega^2 L_1 C_x << 1)$, and ignore $\omega^2 C_x^2 r r_t$ and $\omega^2 C_x^2 r_t^2$,]

* where r_s is the resistance in series with the variable standard capacitor, C_s.

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$$e_2 = e_g \frac{(1 - \omega^2 L_1 C_x)(1 + n - \omega^2 L_1 C_x) + j(1 + n)\omega C_x r - j\omega C_x r_t}{(1 + n - \omega^2 L_1 C_x)^2} \tag{7}$$

For complete compensation, e_o must equal zero.

$$e_o = e_1 - e_2 - e' = 0$$

and,

$$e' = e_1 - e_2 = e'' - je''' \tag{8}$$

With negligible error we can equate the real portion of this expression to the induced secondary voltage, e', and ignore, for the moment, the quadrature term which compensates for the loss in r and r_s.

$$e'' \simeq e' = ji_2\omega M = e_g(j\omega M)/-j(1 + n - \omega^2 L_1 C_x)/\omega C_x = -e_g \omega^2 M C_x/(1 + n - \omega^2 L_1 C_x) \tag{9}$$

It is the real portion of this voltage that compensates for the series inductance in the test arm and test terminals. The circuit elements for this compensation are found by equating e' of Eq. 9, and e" of Eq. 8 (the real part).

$$\frac{\omega^2 M C_x}{1 + n - \omega^2 L_1 C_x} = -\frac{1 - \omega^2 L_1 C_x}{1 + n - \omega^2 L_1 C_x} + \frac{1}{1 + n} \tag{10}$$

From which,

$$M = L_1[n/(1 + n)] = k\sqrt{L_1 L_2} \tag{11}$$

This value of M can be realized by selecting a suitable value of L_2 and adjusting the coefficient of coupling, k. In the 35A Q-Bridge, L_2 and k are fixed so that e" is somewhat greater than required, and Z_B (which is actually an inductor, L-203) is adjusted to cancel the effect of L_1. Z_A is then selected to develop a quadrature voltage of the correct phase to cancel the effect of loss in the lower arms of the bridge. This voltage is e"'.

The quadrature component of Eq. 8, e"' , may be found by expanding the terms, i.e., subtracting e_2 from e_1, and taking the imaginary term. From this we find,

$$e''' = +je_g(n\omega C_x r - \omega C_x r_s)/(1 + n - \omega^2 L_1 C_x)^2 \tag{12}$$

It is evident from this expression that if $nr = r_s$, e"' will be zero, viz., no quadrature voltage is needed. In the bridge section of the 35A, r_s is not sufficiently large to satisfy this relationship, and a phase shift is needed to develop a small value of e"'.

With negligible error we can find the magnitude of e" by substituting Eq. 11 for M in Eq. 9. From which,

$$e'' = e_g n\omega^2 L_1 C_x/(1 + n)(1 + n - \omega^2 L_1 C_x) \tag{13}$$

Using Eq's. 12 and 13, we can write,

$$\tan\theta = e'''/e'' = \frac{\omega C_x(nr - r_s)(1 + n - \omega^2 L_1 C_x)(1 + n)}{(1 + n - \omega^2 L_1 C_x)^2 n\omega^2 L_1 C_x} \qquad (14)$$

and,

$$\tan\theta \simeq (nr - r_s)/n\omega L_1 = 1/Q - 1/nQ'_s \qquad (15)$$

where,

$$Q = \frac{\text{(residual inductive reactance of the test arm)}}{\text{(residual series resistance of the test arm)}}$$

$$= \omega L_1/r$$

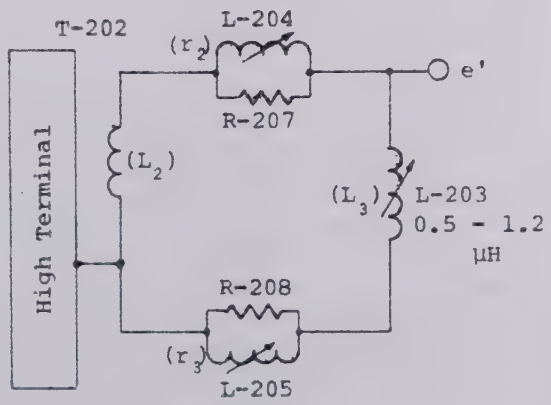
and,

$$Q'_s = \frac{\text{(residual inductive reactance of the test arm)}}{\text{(residual series resistance of the standard arm)}}$$

$$= \omega L_1/r_s$$

It should be made clear that the residual parameters of the bridge are not known (for magnitude or phase), and computations for θ, e', M, or any of the other terms just presented cannot be made with sufficient accuracy to permit a theoretical design of Z_A and Z_B to achieve the proper magnitude and phase from the output transformer for compensation of the inductance and resistance in the test arm and terminals. Because the source impedance of the transformer is largely inductive, Z_B must also be inductive so that the voltage, e', is essentially in phase with the source voltage. To provide a small phase shift, and to permit the phase to swing either side of its normal position, Z_A is made resistive and some resistance is added to Z_B. The resistances are made proportional to frequency, but the rate of change is not necessarily equal for both Z_A and Z_B, so that the phase shift can change with frequency, as required. The circuit is shown in Figure 3. Note that the circuits which introduce resistance to the network actually consist of resistance and inductance in parallel. The circuit Q's are in the neighborhood of one. The behavior of such circuits is described in Boonton's Applications Note #15.

The elements of this network exist in most of the 35A Q-Bridges made by Boonton Electronics during the past few years, and instruments of recent manufacture will have components similar to those shown. Older versions may have somewhat different components. For example, a variable resistor may have been used where a fixed resistor is now shown. In general, the comments which will be given regarding the adjustment of the circuit elements, should be true for all Model 35A Q-Bridges made before 1977. The component values shown are nominal values.



Nominal Values

L-204 = 80 nH, L-205 = 130 nH
R-207 = 100 Ω, R-208 = 24 Ω

Figure 3.

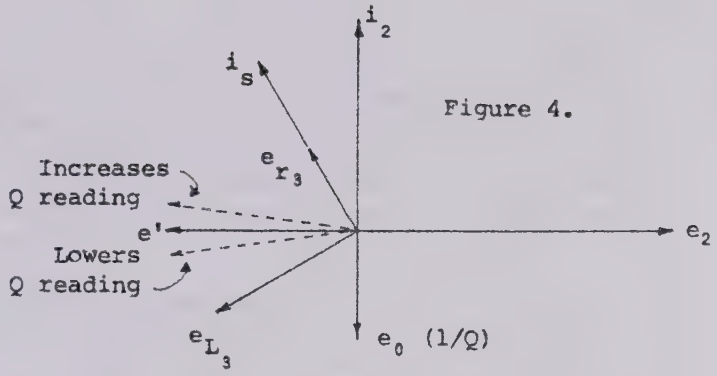


Figure 4.

Figure 4 shows the vector relationship of some of the voltages and currents associated with the output transformer of the Q-Bridge. The vectors are not to scale, but the subject of interest is the phase of the voltage, e', which is the voltage across Z_B, and not the voltage induced in the secondary of the transformer, L_2 of Figure 8 (T-202 of the schematic for the bridge section). We formerly assumed (on page 5) that $Z_A = 0$, and $Z_B = \infty$, and in this case, e' (as used in Eq's. 2, 8, and 9) is the voltage induced in the secondary of the output transformer.

Looking at the vectors, i_s is the current in the secondary circuit of the output transformer. Its angle, relative to the induced voltage, depends upon the impedance of the secondary circuit, including the effective resistance of the parallel combination of L-204 and R-207. This is denoted as r_2 in Figure 3. Incidentally, the effective inductance of this parallel combination is absorbed in L_2, and similarly, the effective inductance of the parallel combination of L-205 and R-208 is absorbed in L_3 (L-203).

It is now fairly obvious that if r_2 is decreased in value, i_s will rotate clockwise, as will e', and the resulting quadrature component of e' will subtract from e_0, causing the Q reading to be higher. If r_3 is decreased, however, e' will rotate counter-clockwise, and the Q reading will decrease.

What is not so obvious is the direction in which the effective series resistance of these parallel circuits of inductance and resistance changes for variations of either frequency or circuit resistance. As mentioned earlier, the subject is covered in Boonton's Applications Note #15. Briefly, the parallel LR circuit works as follows.

> If the circuit Q at the frequency of interest is less than unity, increasing the parallel resistance will increase the effective series resistance, and vice versa. The series resistance will also increase if the inductance or frequency is increased, and vice versa.
>
> When the circuit Q is greater than unity, increasing the parallel resistance will lower the effective series resistance, and vice versa. In this case, however, lowering the frequency, or the inductance will also lower the series resistance, and vice versa.

It is imperative, of course, to keep these facts in mind when attempting to raise or lower the circuit resistance in order to permit two capacitors to stack properly. The problem is compounded when working with the combination of L-205 and R-208. At 50 MHz the Q of this circuit will most likely be less than unity, but at 20 MHz its Q will exceed unity, and this is proper for this circuit. If, for example, R-208 is decreased in value to allow the stacked Q to increase at 20 MHz, it will have the opposite effect on the stacking at 50 MHz, and an adjustment of the L-204/R207 circuit will have to be made.

The first adjustment of the network across the output of the bridge transformer should be for the magnitude of e', which will compensate for the series inductance of the test arm and terminals. A capacitor that measures about 200 pF at 1 MHz, and whose value at 50 MHz is known, will be needed. Or else, the residual series inductance of the capacitor must be known, and the apparent capacitance at 50 MHz can be calculated. There are several well known methods of measuring this parameter.

After the apparent capacitance at 50 MHz has been determined, the 35A Q-Bridge should be adjusted for normal operation at 50 MHz, and the capacitor secured under the binding posts (at the spacing for which the instrument is to be compensated.....normally 3/4" between centers). If the bridge does not balance at the correct reading of capacitance, i.e., the 50 MHz value, not the value at 1 MHz for we should not compensate for the residual inductance of the capacitor, adjust L-203 until balance occurs at the correct dial reading. At this point the indicated value of Q is not significant.

The phase shifting elements of this network must now be adjusted to provide the proper stacking of two 100 pF capacitors at frequencies of 50, 35, and 20 MHz. A description of the technique for the stacking of smaller values of capacitance will be given later.

The 100 pF capacitors should be a high Q type of rf capacitor with porcelain dielectric and silver ribbon leads. A few manufacturers of this type of capacitor are:

Manufacturer	Type
American Technical Ceramics	ATC-100
Dielectric Laboratories, Inc.	11AH & 17AH
Erie Technological Products, Inc.	C3G

A number of these capacitors should be available so that a pair may be matched for equal, or nearly equal Q values. The capacitances should be within a few picofarads of each other. They should be identified. A uniform connection technique should be developed, and we recommend the following:

1. Connect the first capacitor under the front of each binding post on the 35A Q-Bridge, and tighten the posts to secure the capacitor. Adjust both the capacitance dial and the Q balance controls until a null is obtained with a Q reading of 2000. This should be a positive Q (see the the bottom of page 4 and the top of page 5).

2. Remove the first capacitor and connect the second capacitor under the rear of each binding post. Tighten the posts securely. Balance the bridge using only the capacitance dial and read the measured value of Q. It should, of course, be close to 2000 (positive).

3. Loosen the binding posts and insert the first capacitor in its original position under the front of the posts, with the second capacitor remaining under the rear of the posts. Again tighten the

posts and balance the bridge with only the capacitance dial. Read the value of the measured Q of the paralleled capacitors. Check the polarity of the Q reading.

NOTE: Before measuring the first capacitor, the bridge should be fully balanced in the normal manner. As each measurement is made, a reference reading of Q = 1 should be set with the Q Divider in the normal manner. In fact, the only departure from a normal group of three Q readings is the adjustment of the Q balance controls for a reading of +2000 for the first capacitor.

After making the proper adjustment(s) to yield the correct Q reading for the paralleled capacitors, the process must be repeated at the other frequencies recommended, or whatever frequencies are most important to your operation. They will, of course, have to be repeated, for there will be an interaction.

The following Table and graphs were developed to assist in compensating the bridge to achieve satisfactory results with the stacking of capacitors of approximately 100 pF. When the bridge is adjusted later for the stacking of smaller values of capacitance, using another technique, and checked at 100 pF stacking for possible interaction, the bridge should stack (within its specified accuracy) for all values of capacitance.

The procedure for compensation now reduces to a tedious operation of experimentally adjusting, or changing one or more of four components at several frequencies to provide the necessary circuit parameters to negate the effects of rf resistance in critical paths of the bridge circuit. May we say with all candor, Good Luck.

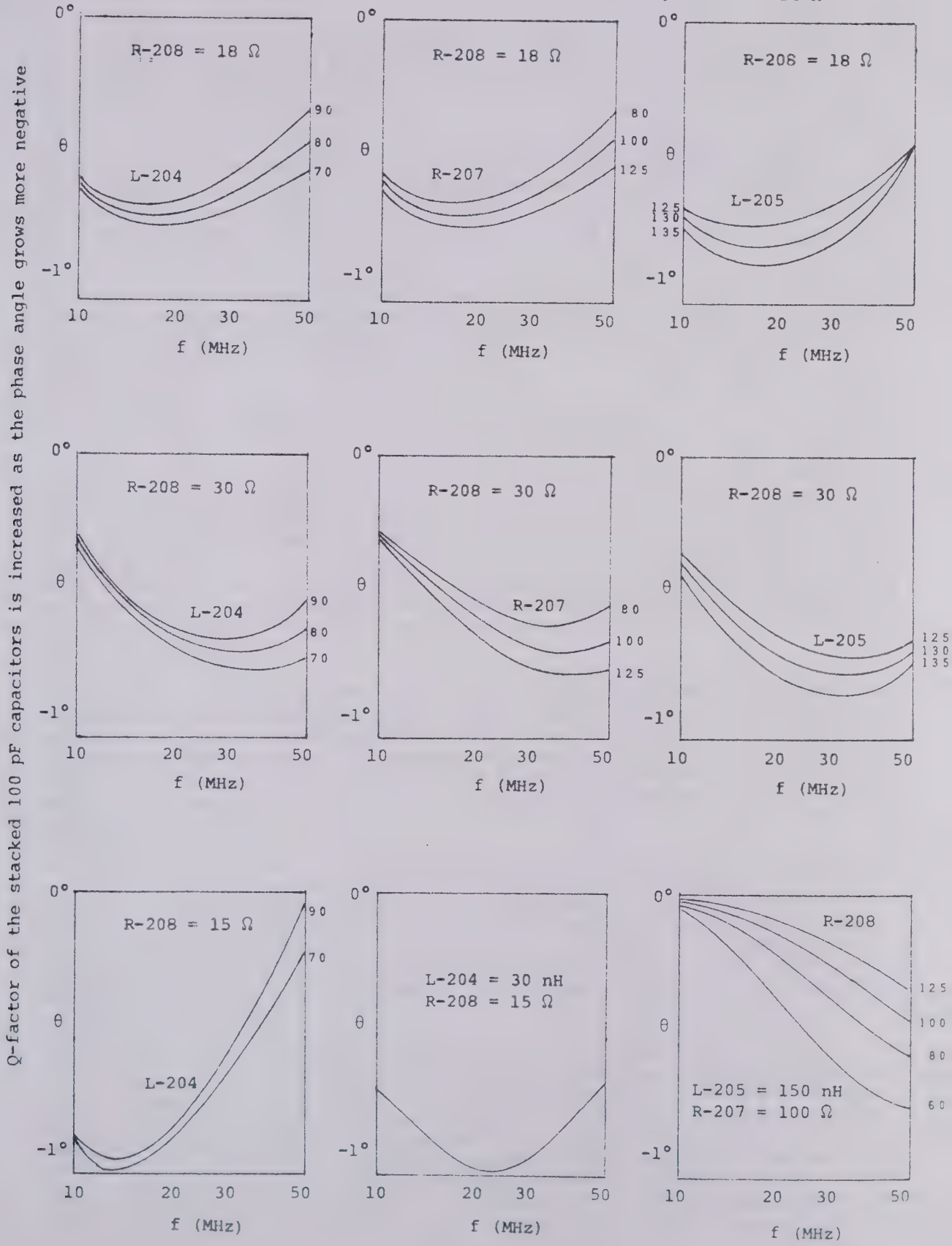
TABLE I

Frequency (MHz)	The combined Q-factor of two 100 pF capacitors stack:	To permit them to stacker higher
50	low	Decrease L-204, or Increase R-207
20	low	Increase L-205, or Decrease R-208*
35	low	Increase R-208, then Decrease R-207 & L-204 to restore proper stacking at 50 MHz. †

* This will affect the stacking at 50 MHz

† In a few instances it has been necessary to connect a parallel resonant circuit across the combination of L-204 & R-207. A 22 pF Duramica capacitor in a DM-15 package with about 14 turns of #24 wire wound on it will resonate at about 35 MHz. The turns may be spread or squeezed, or changed until it tunes at 35 MHz. Adjustments of L-204 & R-207 can be made at 50 MHz, and checked at 35 MHz, until a good compromise obtains.

Unless otherwise indicated, values are: L-204 = 80 nH, L-205 = 130 nH
R-207 = 100 Ω, R-208 = 24 Ω



Q-factor of the stacked 100 pF capacitors is increased as the phase angle grows more negative

Figure 5.

A number of graphs are presented in Figure 5 to explain the manner in which the phase changes as a function of both frequency and circuit elements. A significant amount of information is contained in these curves, and they should be studied carefully.

Looking at the curves, it is evident that the stacking at 50 MHz is controlled by L-204 & R-207. It is also evident that R-208 has an influence on the stacking at 50 MHz, but it also has a pronounced effect at the low and mid frequency range (10 to 30 MHz). L-205, on the other hand, does little at 50 MHz, but controls the stacking at the low and mid frequencies.

We would like to assure those who attempt to compensate the bridge that the circuit adjustments offer a wide range of control, and that satisfactory compensation is attainable. The stacking of the two 100 pF capacitors will not be perfect at all frequencies, of course, but in general, the accuracy stated for the Model 35A Q-Bridge will obtain if the stacking is within 10 to 15%.

Variable loss in the variable standard capacitor

At minimum capacitance and at the higher frequencies the three-terminal configuration of the standard capacitor makes it prone to develop a negative conductance component owing to the presence of resistance in the shunt arm to ground. This resistance is manifest in two places. The baffles which are tightly coupled at minimum capacitance, and the conductance loss in the insulated bearings. This loss is in parallel with the capacitance of the bearings and at high frequencies produces an equivalent series resistance in the shunt arm of the capacitor. This subject is covered in more detail in Boonton's Applications Note #15.

As the capacitor plates engage, this effect diminishes and the loss in the capacitor approaches zero (or at least is constant). As the capacitor is rotated from its minimum dial reading of 20 pF, this effect causes the Q of the capacitor to worsen, i.e., it changes from some negative Q-factor to a less negative Q-factor. This worsening of the Q-factor of the standard capacitor makes a test specimen, or two 22 pF stacked capacitors,appear to have a higher Q-factor than actual.

The solution to this lies in the introduction of positive loss that must be coupled to the rotor plates in such a way as to divorce itself as the plates engage, and at the correct rate of divorcement, and the loss must also reduce as the frequency is lowered. A resistor shunted with an inductor with one terminal connected to a set of stator plates and the other having a wire lead to couple capacitively to the tip of the rotor plates of that same capacitor section will provide the necessary properties to negate the negative loss in the capacitor.

The selection process for the value of the resistor and the inductor that parallels it, and the juxtaposition of the wire coupling lead to the end of the rotor plates is taxing, to say the least. Hopefully, the circuit which was installed at the factory may need only an adjustment of the coupling lead, or perhaps a small change in a component value. If the parallel RL circuit is in place, stacking should be checked with two nearly identical 22 pF capacitors, and either two 33 pF or two 47 pF capacitors of the same type as the 100 pF capacitors used previously. The first check should be made at 50 MHz, and if the stacking is reasonably good it should be checked at other frequencies, such as 35 and 20 MHz. We urge that you do not change the component

values until the bridge stacks properly at 50 MHz, and tests at lower frequencies prove the need for other values of either resistance or inductance.

It will be evident that at any one frequency, any reasonable combinatior of resistance and inductance (or even resistance alone) can be coupled to stack a pair of 22 pF capacitors. When attempting to stack 22 pF capacitors, as well as, say, 47 pF capacitors, the shape of the wire coupling lead is significant, for it obviously determines the manner in which the coupling is reduced. As the frequency is reduced, after stacking at 50 MHz, the ratio of L/r is of consequence in establishing the roll-off with frequency.

While it is good to get an approximate positioning of the coupling wire for both pairs of stacking capacitors, you should not spend too much time on this phase of the operation before checking the stacking at other frequencies. It will often be necessary to change the inductor or resistor, or both, to achieve the needed results, and this rework will undo the carefully placed coupling lead.

If, after several adjustments, the solution seems hopeless and you become desperate (strong men have wept over this procedure), it might be advisable to try this technique.

Substitute a miniature, single-turn potentiometer of 250 ohms for the loss network of resistance and inductance. Solder one terminal to the stator plates and extend a short wire lead to couple to the end of the rotor plates with the capacitor set to read 20 pF. The potentiometer should be rigid so that adjustments will not change the position of the coupling lead.

Set the resistance, as measured on a dc digital ohmmeter, to a value of 200 ohms, and shape the coupling wire for proper stacking with both pairs of capacitors. Then lower the frequency to, say, 40, 30, and 20 MHz and adjust and note the resistance require for stacking. If other frequencies are important, they should be used.

Here is a typical example using this technique. A potentiometer is adjusted in the manner described above with the following results.

f (MHz)	Resistance (Ω)
50	200
40	190
30	180
20	135
10	64

A plot of these values should be made on log-log graph paper of the same scale as Figure 1 in Applications Note #15 (1 cycle per 3.75 inches). When this curve is superimposed on the normalized curve of r_s in Figure 1, the best fit will occur when the 16 MHz ordinate coincides with the Q = 1 ordinate of Figure 1. The corresponding value of equivalent series resistance at this point is about 111 ohms. Because the Q of the circuit is 1 at this frequency, the actual parallel resistance is twice this, or 222 ohms. The inductive reactance is also 222 ohms, which is derived from 2.2 μH of inductance. A parallel circuit of 2.2 μH and 220 ohms will yield a suitable series resistance at the frequencies listed above, and should be good over the entire range.

Q Balance

If the adjustments and calibration described so far have been done satisfactorily, the final procedure is to set the loss in the internal 20 pF standard capacitor so that when the Q balance control is adjusted at each frequency for a meter reading of $Q = \infty$, the Q standards will read correctly. This distributes the bridge loss and permits the 35A to measure the effective Q-factor of the test specimen.

There are two means of setting the correct position of the Q balance control. One uses a set of Q standards, the other employs a special technique that was developed for the 35A Q-Bridge prior to the development of a full set of Q standards.

Q standard method

A limited number of Model 35-8A Q Standards are available from Boonton Electronics. They are specified as follows:

Model	Frequency	Q-Factor	Uncertainty
35-8A/1	1 MHz	500	5%
35-8A/2	1 MHz	1500	8%
35-8A/3	1 MHz	5000	15%
35-8A/4	20 MHz	1500	20%
35-8A/5	50 MHz	500	20%

The 35-8A Q Standards fall into two categories. Those that are used at 1 MHz, and to a limited extent above and below 1 MHz, and those that are used at higher frequencies.

Because the electrical parameters in the 1 MHz standards are quite predictable, the effective Q-factors of these standards can be calculated, and the uncertainty of the value of Q is lower for these standards than it is for the higher frequency Q standards. The Q-factors of the 1 MHz Q standards are inversely proportional to frequency, so with somewhat increased uncertainty, they may be used at frequencies of 200 kHz to 5 MHz, except for the 35-8A/3 which should not be used below 500 kHz.

These 1 MHz Q standards are fully described in Boonton's Applications Note #13, "Calculable 1 MHz Capacitive Q Standrads".

At higher frequencies the intrinsic Q-factors of the principal capacitors used in the standards decrease to values that are only several times greater than the desired Q of the standard. The effective Q of such a standard depends significantly upon the measured Q of the capacitor, as well as the calculable loss which is added to the capacitor. A better method is to provide an adjustable loss network which lowers the Q-factor of the combination to the desired value at the proper frequency. The entire unit is measured and adjusted until the desired Q-factor obtains.

Additional Q standards will needed if a complete adjustment of the Q-Bridge is to be made at intervals of, say, 10 MHz. If the need is sufficiently great, stable capacitors may be mounted on rexolite blocks equipped with tabs for attachment under the binding posts of the 35A Q-Bridge. These units can then be measured for effective Q-factors with probable uncertainties of less than 10% using resonant coaxial transmission lines. The technique and related

equations are given below. Because of the rigorous interrelationship of the measuring frequency, capacitance, and line length, for a given line you may select the value of capacitance or the measuring frequency, but not both. To make use of a minimum number of transmission lines, the capacitances of the various Q standards should differ so that one line may be used at several frequencies.

The principle of measuring the Q-factors of capacitors with a resonant line is simple. A measurement of frequency is made each side of resonance on the unloaded line, and again on the loaded line. In addition to the line, only a good signal generator and rf millivoltmeter are needed.

A stable signal generator should be coupled loosely to the short-circuited end of the line, and the probe of an rf millivoltmeter should be coupled loosely to the open-circuited end of the line. The outer-to-center conductor spacing of the line should be compatible with the terminal spacing of the Q standards to be measured.....about 3/4 inch. The line spacing must not be too small or the intrinsic Q-factor of the line will suffer, as will the uncertainty of the measurement of the Q standard.

A digital display of the output frequency of the signal generator must be available, either from the generator or a counter. The rf millivoltmeter should have a full-scale sensitivity of 1 millivolt, but will most likely be used on the 3 and 10 millivolt ranges. A calibration of the full & half voltage points on these scales should be made. A convenient way to couple the rf millivoltmeter to the center conductor is to drill and tap a hole in the outer wall of the line which will accommodate the tip of the probe.

Tune the generator to the quarter-wavelength resonant frequency of the line (the three quarter-wavelength resonant frequency may also be used), and adjust the generator output and frequency for a full-scale reading of 10 mV, if possible. Carefully tune to each side of resonance (the half-voltage points give the best accuracy) and note the two frequencies to at least six significant digits. The Q-factor of the line at f_0 may be found from:

$$Q_0 = (f_0/\Delta f)\sqrt{m^2 - 1}$$

Q_0 denotes the measured Q-factor of the unloaded line, m is the ratio of resonant to off-resonant voltage, and Δf equals the total bandwidth between the off-resonant voltage points. If the half-voltage points are used, the equation reduces to:

$$Q_0 = \sqrt{3}(f_0/\Delta f)$$

The capacitor (Q standard) can now be connected across the open end of the line, and resonance will occur at some lower frequency, f_1, where the reactance of the line equals the reactance of the capacitor. The generator frequency is adjusted above and below resonance where the coupled voltage falls to one-half its resonant value. The Q-factor of the capacitor may be found with the following equation.

$$Q_C = \frac{\cos \beta_1 \ell}{\sqrt{D_1 D_2/3} - (\pi/4Q_0)\sqrt{f_1/f_0 D_3}}$$

where,

$$D_1 = \cos \beta_3 \ell - \frac{\sin \beta_3 \ell}{\tan \beta_1 \ell} \frac{f_3}{f_1}$$

$$D_2 = \frac{\sin \beta_2 \ell}{\tan \beta_1 \ell} \frac{f_2}{f_1} - \cos \beta_2 \ell$$

$$D_3 = 1/\sin \beta_1 \ell$$

f_2 and f_3 are the frequencies of the half-voltage points below and above f_1, respectively. $\beta_1 \ell$, $\beta_2 \ell$, and $\beta_3 \ell$ are the electrical lengths of the line at frequencies f_1, f_2, and f_3, respectively.

$$\beta_1 \ell = (f_1/f_0)90°$$

$$\beta_2 \ell = (f_2/f_0)90°$$

$$\beta_3 \ell = (f_3/f_0)90°$$

The relationship of capacitance, frequency, line length, and line impedance is given by:

$$C = \frac{1}{\omega_1 Z_0 \tan(1.91 \times 10^{-9} \omega_1 \ell_{cm})} \qquad \text{(pF)}$$

You will find it convenient to draw a graph of capacitance vs. frequency for each line.

The major requirement for the signal source is frequency stability. Measurements cannot be made with a generator that drifts. The output of the generator should not be modulated. The Boonton Model 102 Signal Generator has been used successfully for such measurements for the past several years. The stability is remarkably good and it provides a six digit display of the output frequency between 10 and 100 MHz, and seven digit resolution above 100 MHz.

A small loop inserted at the shorted end of the line in the radial plane should be sufficient to excite the line and give a suitable reading on a loosely coupled rf millivoltmeter without introducing noticeable loss into the line. A terminating resistor in series with the loop may reduce the swr on the cable between the generator and the resonant line. Whether or not the induced voltage is a function of frequency, however, is of little consequence because of the small deviations needed for these measurements.

There are a few requisites for the rf millivoltmeter: a high impedance probe is important; it should be coupled loosely to the open end of the line;

and both the full-scale and half-scale readings on the ranges to be used should be calibrated. The Boonton Model 92B RF Millivoltmeter is an excellent choice for this application.

With respect to the resonant line, the equation given for Q_c on page 15 assumesthat the entire loss in the line is from series resistance, and that this resistance and the attenuation constant is proportional to $\sqrt{f}$. To satisfy this requirement the line material should be uniform throughout, and should not be plated. If insulated rods or screws are needed to support the center conductor, the number used should be minimized.

There is some, but not much more information concerning this measurement in an article entitled " Measuring Capacitor Loss" which appeared in the November 22, 1976 edition of Electronic Design, pp 130 - 133.

After a sufficient number of Q standards have been calibrated, the 35A Q-Bridge should be turned on and allowed to warm up, prior to the calibration of the internal 20 pF standard capacitor for the adjustment of loss.

Specific instructions for adjusting the loss will be given later, but the general procedure for using the Q standards is as follows. Set up the Bridge in the normal manner, balancing for $Q = \infty$ with the internal 20 pF standard push-button engaged. Connect the Q standard and balance the Bridge for a maximum reading, setting the gain of the system with the Q ÷ 1 controls.

If the measured Q-factor is not that of the standard, adjust the Q balance control (generally, only the FINE balance control will need adjustment) for the correct reading. Note whether the control had to be turned clockwise, or counter-clockwise. You should, of course, already established that the Q-factor reading was positive, as explained on pages 4 & 5. If the control needed to be turned to the right (clockwise), the Q of the internal 20 pF standard is too high and some negative loss should be removed from the capacitor.

The measurements using the Q standards must be made with the top plate in place, and with all screws tightened securely. Adjustments to the 20 pF standard capacitor, however, cannot be made without removing the top plate, and furthermore the validity of the adjustment cannot be determined until the top plate is reinstalled. From all of which you will agree that the process is a demanding one which requires much patience.

ΔCΔQ technique

If air capacitors could be built with Q-factors that were sensibly infinite, the need for Q standards would be eliminated, and the Q balance control would be adjusted until these capacitors balanced to infinity, then the loss across the internal 20 pF standard could be made compatible with this Q balance setting. Unfortunately, even the Q-factor of a simple pair of copper plates is perceptibily less than infinity at the higher frequencies of 20 to 50 MHz. If however, a simple adjustable air capacitor is constructed so that the loss is entirely the result of series resistance, and this resistance is constant at any one frequency and independent of capacitance, it can be instrumental in determining the correct setting of the Q balance control. This assumption is based upon a proper calibration of the tuned voltmeter/detector and suitable compensating adjustments which provide adequate stacking of capacitance.

The usefulness of such a capacitor is evident if we consider a variable capacitor whose value changes from C_1 to C_2 while the series resistance, r, remains constant. For this, we can write:

$$Q_1 = 1/\omega C_1 r$$

and,

$$Q_2 = 1/\omega C_2 r$$

Dividing,

$$Q_1/Q_2 = C_2/C_1$$

and,

$$C_1 Q_1 = C_2 Q_2$$

The significance of this is that as the capacitance is, say, decreased, the measured Q-factor should increase in direct proportion, and it will if the Q balance control is properly set. This also means that both the measured Q-factors are correct, but, of course, there is no way to verify this. We must depend upon the inverse linear relationship between capacitance and the indicated Q-factor. In practice, it is prudent to make a series of measurements of decreasing capacitance and increasing Q-factors, and to plot these values on log-log graph paper, as shown in Figure 6. When the plotted values fall on a straight line with a slope of -1, the Q balance control is set correctly. The measured Q-factors will not fit perfectly, but should be within acceptable limits.

If the Q balance control is too far counter-clockwise, the plotted curve will be somewhat convex, and if it is clockwise from the correct setting, the curve will be concave.

Because the adjustable capacitor is vital to the successful calibration of the Q-Bridge, it is worthy of a full description. One plate is a brass disc slightly larger than the diameter of a Bridge terminal post. Soldered to the disc is a segmented ring which clamps to the low terminal post. The other plate is made from a sheet of brass, about 0.1 inch thick, 1.8 inches long, and slightly more than an inch wide (about the same dimension as the diameter of the brass disc). Approximately half of the length is undercut. The thicker end of this plate mounts on the high terminal post and the thinner end extends over the brass disc which is pressed on to the low terminal post. A sketch of these two pieces is shown in Figure 7.

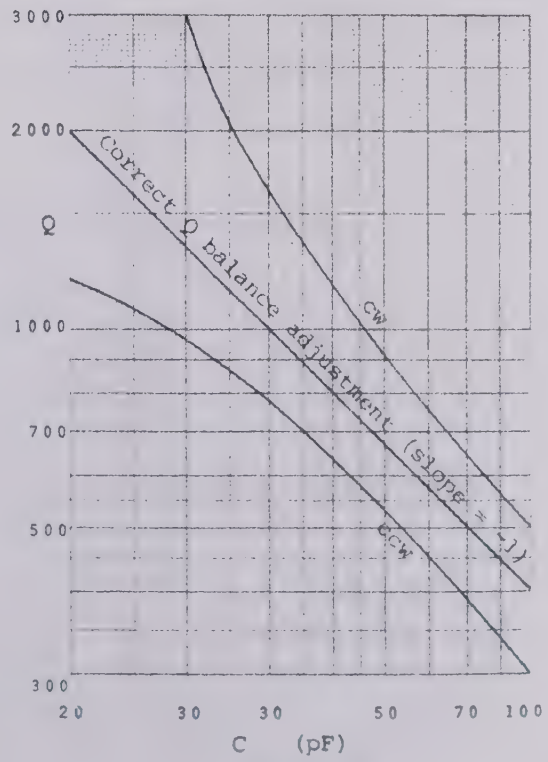


Figure 6.

An advantage of considerable importance offered by this technique is the immunity to error caused by series inductance. This is shown in the following derivation, and it permits us to insulate the second plate with a mica washer and nylon

screw, and make a connection with additional resistance from a lug on the brass plate to an unused terminal on the high terminal post. This resistance may take the form of a thin piece of copper wire at the higher frequencies; a short length of resistance wire at the mid frequencies; or an actual carbon resistor of 1 to 10 ohms at the lower frequencies.

This resistance is needed, especially at the mid and lower frequencies, to permit on-scale readings of the measured Q-factors. Not only should the readings be on scale, however, but at the lowest capacitance setting of about 20 or 30 pF for the adjustable air capacitor, the measured Q-factor should not exceed 3000 to 4000. This will suppress the influence of noise (meter unrest) on the meter reading.

The presence of inductance in the connecting link between the plate and high post will cause the apparent, thus the measured capacitance to be greater than the actual capacitance between the plate and the disc, but provided the inductance remains fixed as the disc moves away from the plate, and the capacitance decreases, this inductance will not affect the measurement.

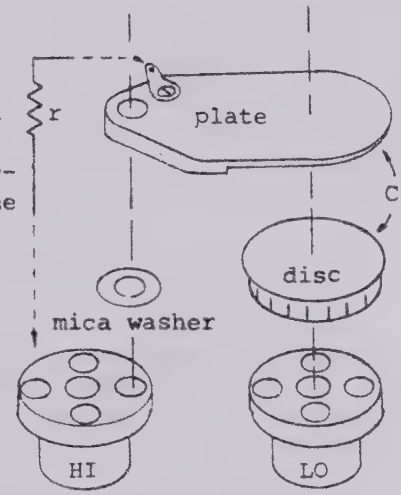


Figure 7.

$$C_{m_1} = C_1/(1 - \omega^2 LC_1)$$

$$Q_{m_1} = (1 - \omega^2 LC_1)/\omega C_1 r$$

$$C_{m_2} = C_2/(1 - \omega^2 LC_2)$$

$$Q_{m_2} = (1 - \omega^2 LC_2)/\omega C_2 r$$

and,

$$\frac{Q_{m_1}}{Q_{m_2}} = \frac{(1 - \omega^2 LC_1)\omega C_2 r}{(1 - \omega^2 LC_2)\omega C_1 r} = \frac{C_{m_2}}{C_{m_1}}$$

Because we are comparing measured values of capacitance and measured Q-factors, the relationship is identical to the one presented earlier.

The adjustment of the air capacitor deserves mention. The undercut of the plate should be such that when the plate is secured to the high terminal post, the disc must be raised about 0.05 inch to make contact with the plate. At this point, of course, the capacitor is shorted. The technique to free the disc from contacting the plate, and still maintain an extremely close spacing so that the capacitance will be high (> 100 pF), is one that requires some practice. It can be done by tapping the thin end of the plate with a finger nail, or the eraser end of a pencil. This is a delicate operation and must be done with finesse.

At high frequencies, the problem can be alleviated by coiling the wire that introduces resistance in series with the capacitor and the high post so that some inductance is also added to the circuit. This will effectively increase the capacitance for a given spacing of the plate and disc. Successsive readings of the Q-factor for diminishing values of capacitance, for different settings of the Q balance control, should eventually lead you to a position on the control that will yield a constant product (very nearly) of capacitance and Q-factor.

At this point the Q-Bridge will correctly measure the Q-factor of capacitors, and several Q standards should be established, using a number of different values of capacitance. The capacitors assigned for this function should preferably be the type used for stacking, or at least a high quality silvered mica.

The frequency should be changed and the process repeated, with new standards being generated at each frequency. The same capacitors can be used provided the Q-factors are not too high. Q-factors of more than about 5000 are subject to measurement uncertainty owing to the meter unrest caused by amplifier noise. It should be noted that the system sensitivity requires a Q-factor reading of 10,000 for an input signal of about 2 microvolts.

Once a sufficient number of Q standards have been developed, the internal 20 pF standard capacitor can be compensated for loss to allow the Q balance control to be set to its proper position at each frequency when the bridge, with the 20 pF capacitor engaged, is adjusted for a null, or $Q = \infty$.

Internal 20 pF capacitor

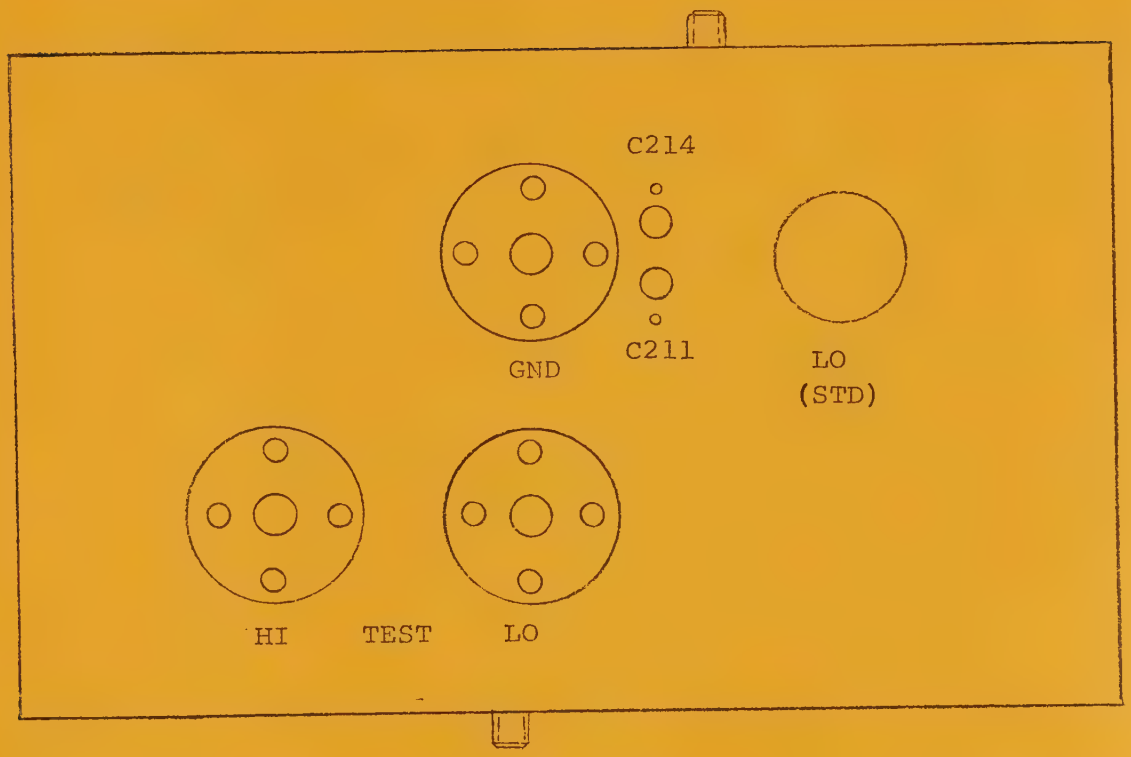
The internal 20 pF standard capacitor comes close to being sensibly lossless, but the contacting fingers which place it in and out of the circuit, and the total conducting path have sufficient resistance to produce a capacitance standard with less than the required value of Q. The capacitor, therefore, needs some form of negative conductance , but to various degrees at different frequencies. Two tee networks are usually adequate to furnish the needed negative conductance.

A network that predominates at the higher frequencies consists of two 1 pF capacitors in series, connected directly across the 20 pF standard capacitor. The junction of these two capacitors is returned to ground through a parallel combination of resistance and inductance. Nominal values for the resistance fall between 22 and 47 ohms. The inductance obtains with about 6 to 9 turns of #34 wire, close spaced, wound directly over the body of the 1/4 watt resistor. This circuit offers a negative conductance to the 20 pF standard capacitor that diminishes with frequency. The rate of decay depends upon the ratio and magnitude of the inductance and resistance. Small adjustments of inductance are possible by modifying the spacing of the turns of wire on the resistor.

At the lower frequencies the compensating network is also a tee configuration that employs a fixed 1 pF capacitor in series with a variable capacitor of 0.8 to 3.0 pF. The junction returns to ground through a 220 kΩ resistor, which is paralleled by a capacitor of about 75 pF. This capacitor is selected at 1 MHz for a null, following the setting of the Q balance control with a 1 MHz Q standard. The series capacitor adjusts the loss at 300 kHz. Several passes must be made to attenuate the interaction, and we suggest the adjustent start with the variable capacitor.

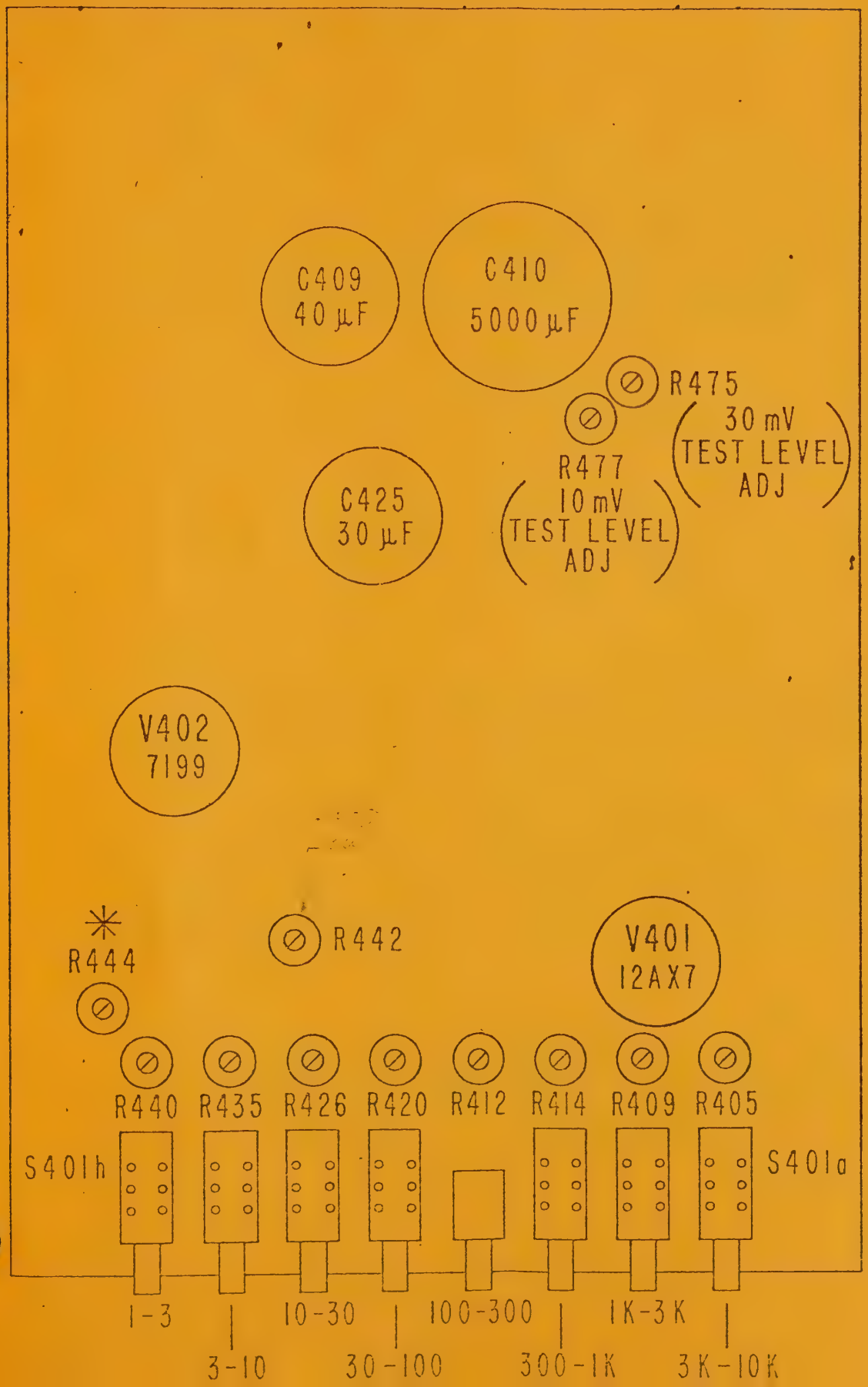
R. E. L.
3/1/77

CONNECT BRIDGE
SOURCE HERE



OUTPUT OF
BRIDGE

35A TOP PLATE


C409
40 µF
C410
5000 µF
R475
30 mV
TEST LEVEL
ADJ
R477
10 mV
TEST LEVEL
ADJ
C425
30 µF
V402
7199
R444
R442
V401
12AX7
R440
R435
R426
R420
R412
R414
R409
R405
S401h
S401a
1-3
3-10
10-30
30-100
100-300
300-1K
1K-3K
3K-10K

CHAPTER V

TEST AND MAINTENANCE

The Model 35AQ Bridge is designed and built to give years of trouble-free service. However, as with any laboratory instrument of this complexity, it is advisable to establish a periodic test program to check its calibration and general performance at regular intervals. The procedures that follow will enable the user to maintain the instrument in dependable working condition, and require a minimum of test equipment.

Equipment Required

Frequency Counter, 0.1 MHz to 50 MHz
RF Voltmeter, BEC Model 92 Series
DC Power Supply, 0 to 200 vdc
Simpson VOM Model 260
BEC Q Standard 35-8A/1
AC Voltmeter (BEC 93A or equivalent)

5.1 Preliminary Steps

The 35A must be removed from its cabinet before starting the calibration procedure. Remove all the black anodized screws from the front, sides, and rear of the instrument. Remove the black anodized screws from around the bridge terminals on the top surface, being careful not to remove the innermost line of plated screws immediately surrounding the terminal plate.

The major subassemblies of the 35A are located as follows: The Detector circuits are housed in the aluminum enclosure nearest the front panel on the right-hand side of the instrument; the Oscillator circuits are in the enclosure to the rear of the Detector, the Bridge components are in the enclosure immediately below the brass terminal plate on the top of the instrument, while the Power Supply circuits are on the PC board to the left of the instrument.

NOTE

The Bridge section of the 35A is a precision assembly, requiring a very high degree of skill and experience to adjust. The user is strongly urged not to attempt any repair or calibration work on this section, but to return the instrument to the factory if malfunction of Bridge components is suspected.

5.2 Oscillator Frequency Calibration

a. Remove the small coverplate at the rear of the oscillator housing, and turn the PULSE switch on the rear apron to OFF. Connect the frequency counter to the LO-STD Type N connector on the brass top plate of the bridge.

b. Starting with the lowest range (0.1 to 0.2 MHz), adjust the inductance trimmer L103 at the low-frequency end of the range and the capacitance trimmer L103 at the high-frequency end until the dial setting and the frequency counter agree within 2%. The two adjustments will usually interact to some extent, and it will be necessary to go from end to end of the band several times before the frequency is correct at each end.

c. Continue this process through the other bands, consulting Table 1 for the correct controls, and the Location Drawing, Figure 9, to identify them. When all 9 bands have been correctly calibrated, replace the rear cover plate and turn the PULSE switch back to ON. Be sure that all the screws for the cover plate are well tightened.

5.3 Detector Tracking Adjustment

a. Remove the small cover plate on the top of the detector housing. Set the MHZ switch to the 0.1 - 0.2 MHz position. Engage the 20 pF STD push-button.

b. With the 100-300 Q RANGE switch button depressed, unbalance the bridge to obtain an "on-scale" reading on the meter.

c. Set the FREQUENCY control to one dial division in from the low-frequency end (0.105 MHz).

d. Adjust inductance trimmer L305 (see Location Drawing, Figure 10, for identification) for the lowest meter reading (minimum Q).

e. Adjust FREQUENCY control to one dial division in from the high-frequency end of the band, and adjust C312 for the lowest meter reading.

f. Repeat each of these two adjustments as required until good tracking is obtained.

g. Repeat this procedure on the remaining 8 bands, following the steps in Table II. Then replace the cover plate and tighten the mounting screws.

5.4 Test Level Calibration

a. Set MHz switch to the 0.2 - 0.4 MHz position, FREQUENCY control to 300 kHz, CAPACITANCE control to 20 pF, and the Q BAL controls to maximum ccw positions. Turn the PULSE switch to OFF.

TABLE I

Band	Frequency	Adjust	Frequency	Adjust
1	0.1 MHz	L103	0.2 MHz	C103
2	0.2 MHz	L104	0.4 MHz	C104
3	0.4 MHz	L105	0.8 MHz	C105
4	0.8 MHz	L106	1.6 MHz	C106
5	1.6 MHz	L107	3.0 MHz	C108
6	3.0 MHz	L108	6.0 MHz	C109
7	6.0 MHz	L109	12 MHz	C110
8	12 MHz	L110	24 MHz	C111
9	24 MHz	L111	50 MHz	C112

See Figure 9

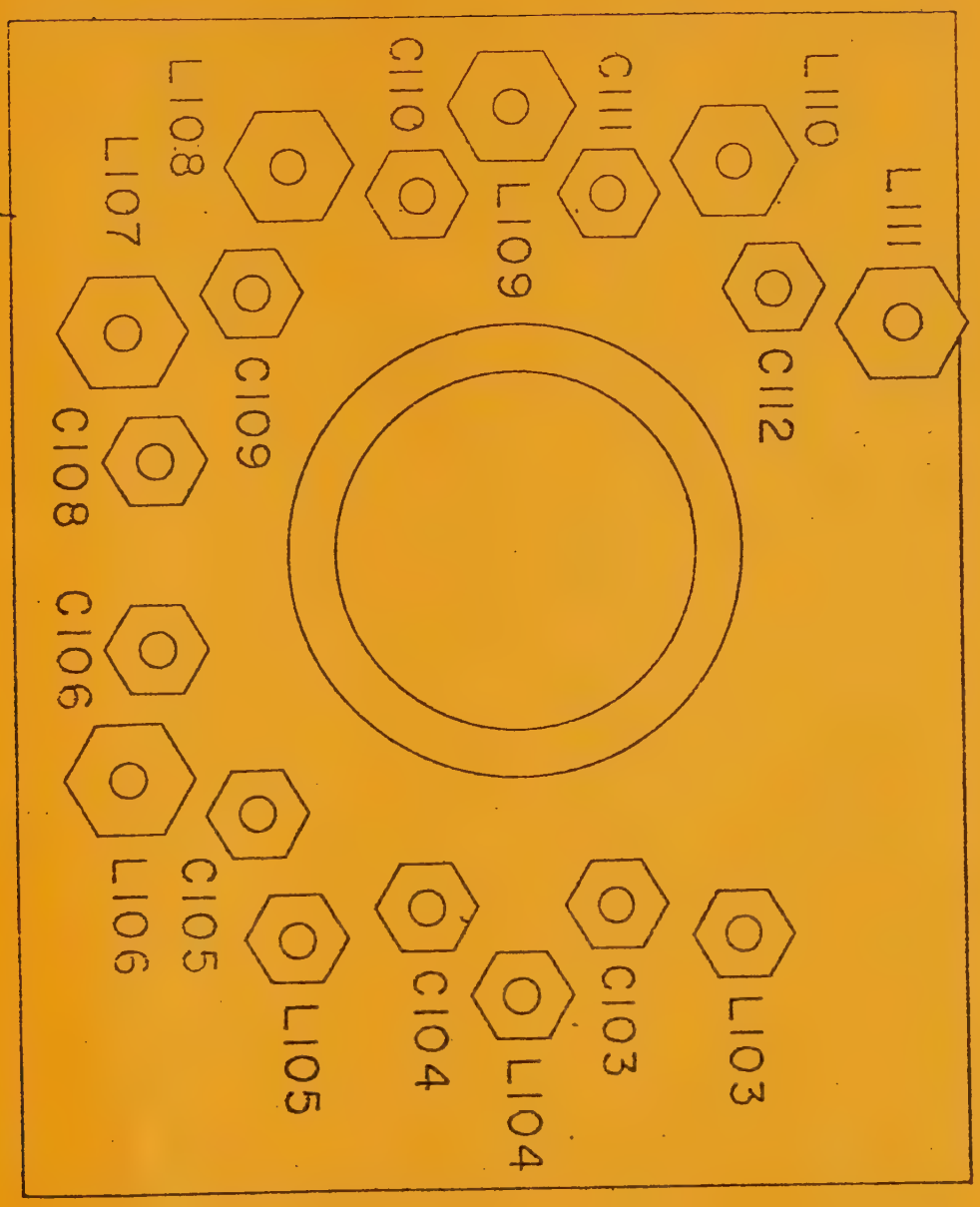


Figure 9. (Oscillator)

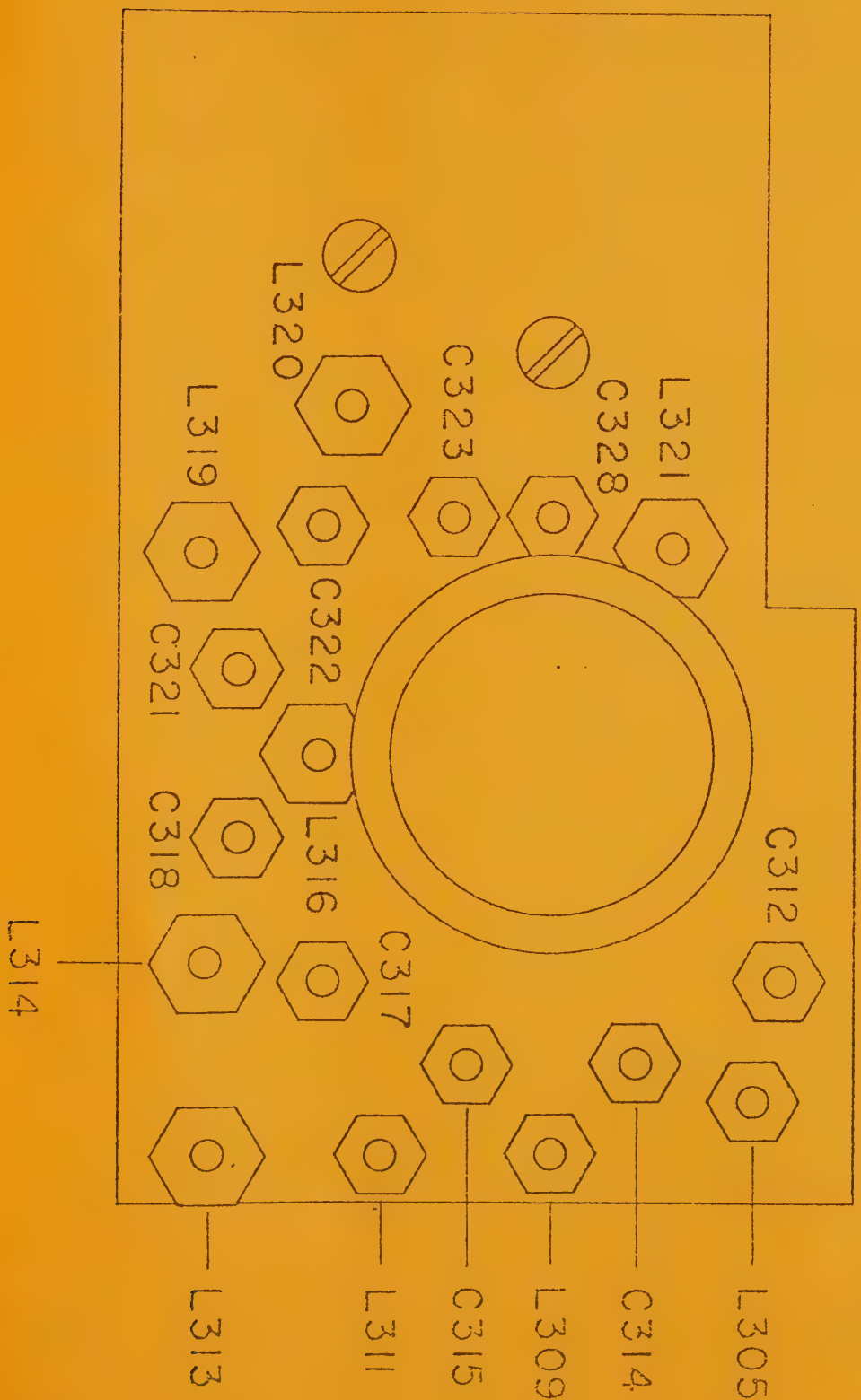
TABLE II

Band	Frequency	Adjust	Frequency	Adjust
1	0.105 MHz	L305	0.195 MHz	C312
2	0.21 MHz	L309	0.39 MHz	C314
3	0.425 MHz	L311	0.775 MHz	C315
4	0.85 MHz	L313	1.55 MHz	C317
5	1.55 MHz	L314	2.95 MHz	C318
6	3.10 MHz	L316	5.90 MHz	C321
7	6.20 MHz	L319	11.8 MHz	C322
8	12.5 MHz	L320	23.5 MHz	C323
9	25.0 MHz	L321	49.0 MHz	C328

See Figure 10.

Figure 10. Location Drawing

Figure 10. (Detector)



b. Connect the RF voltmeter from the LO TEST post to ground. Switch the Pulse Switch to the OFF position.

c. Set the TEST LEVEL control to 10 mV and read the RF voltmeter. If it does not indicate 10 mV, adjust R477 on the Power Supply PC Board for a correct reading. (See Figure 11 to locate this and other controls on this board.)

d. Set the TEST LEVEL control to 30 mV and read the RF voltmeter. Adjust R475 as needed to obtain a correct reading.

e. Repeat steps "c" and "d" as necessary to achieve errors of less than ±2 mV at any point on the TEST LEVEL range.

f. Set the MHZ switch to the 24 - 50 MHz position, and the TEST LEVEL control to 20 mV.

g. Measure the test level at all frequencies between 24 and 50 MHz. If the observed error is greater than ±2 mV at any frequency, set the FREQUENCY control to the point of maximum error and adjust C131 for a reading of 20 mV.

NOTE: Access to C131 is obtained by removing the cover plug at the top of the right-hand side of the Oscillator housing.

5.5 Q Ranging Calibration

a. Locate the coaxial cable running horizontally from the top front of the Bridge housing to the left side of the Detector enclosure, immediately behind the top of the front panel. Disconnect this cable from the Detector input (J301).

b. Connect a 30 dB G. R. attenuator, in series with an adjustable attenuator of 70 dB maximum (50 Ω), between the LO STD Type N connector on the Bridge top plate and the Detector input connector, J301.

c. Turn the PULSE switch to ON, and set the FREQUENCY control to 300 kHz. Set the Q RANGE switch for the 100 - 300 range.

d. Set the adjustable attenuator for 40 dB, then adjust the Q DIVIDER control for an "on-scale" meter reading.

e. Adjust R503 on the Sync Rectifier PC board for a maximum leftward deflection on the meter (lowest Q).

NOTE: The Sync Rectifier PC board is mounted vertically on the left wall of the cabinet; R503 is the rearmost of the two potentiometers on this board.

f. Remove the input coaxial cable from the Sync Rectifier (J402). This is the heavy grey cable in the front group, fourth terminal from the front edge.

g. Short the panel meter terminals together with a small clip lead and adjust the meter's mechanical zero screw for a reading of infinite Q (∞).

h. Remove the jumper from the meter terminals and adjust R516 (front potentiometer) on the Sync Rectifier board for a reading of infinite Q (∞). Replace the input cable to the Sync Rectifier J402.

i. Connect the AC voltmeter to the input of the 700 Hz amplifier (P401). This may be done by clipping the voltmeter lead to the junction of the 681 Ω resistor and the 0.01 μF capacitor located at the front right corner of the Power Supply board, immediately behind the right-hand section of the Q RANGE switch.

j. Adjust the Q DIVIDER control and test level control for a reading of 6 mV on the AC voltmeter. Disconnect the voltmeter once this has been done.

k. Make the Q Range adjustments through the positions of the switch in accordance with Table III following. Refer to Figure 11 to locate the various trimmers on the Master Board.

l. Remove the attenuators and reconnect the Bridge cable to the Detector. This completes the Q Ranging calibration.

5.6 Internal Bias Check

a. Connect the VOM, set on the 250 vdc range, between the HI and LO Monitor terminals on the panel. Set the INTERNAL BIAS switch to the 0 - 100 V position.

b. Turn the ADJ control slowly from the ccw to the cw position while watching the VOM reading. The voltage should increase smoothly from 0 to 100 volts dc.

c. Set the INTERNAL BIAS switch to the 0 - 10 V position, and the VOM to the 50 vdc range. Repeat the test above.

d. Connect the VOM between the HI and LO TEST connectors on the bridge plate and verify that the meter reads the same as when it was connected to the Monitor jacks on the panel.

5.7 External Bias Check

a. Connect the shorting bar between the LO and Ground EXTERNAL BIAS terminals on the panel. Connect the VOM between the bridge HI and LO TEST terminals, and set to the 250 Vdc range. Connect the dc power supply between the HI and LO EXTERNAL BIAS terminals on the panel. Set the INTERNAL BIAS switch to the EXT position.

b. Set the power supply to 200 vdc, and verify that the VOM reads the same.

c. Shift the shorting bar to the HI and Ground EXTERNAL BIAS terminals. Connect the positive power supply lead to the Ground terminal and the negative lead to the LO terminal. Set the output of the power supply to 50 vdc and verify that the VOM reading agrees. Remove the power supply and VOM.

TABLE III

Q Range	Attenuator Setting	Adjustment	Adjust for Q =
100-300	40 dB	R442	100
100-300	50 dB	R412	316
1-3	0 dB	R440	1
3-10	10 dB	R435	3.16
10-30	20 dB	R426	10
30-100	30 dB	R420	31.6
300-1 K	50 dB	R414	316
1 K-3 K	60 dB	R409	1 K
3 K-10 K	70 dB	R405	3.16 K

See drawing 830593 following, Figure 11. Q Ranging Adjustment Location

1. GENERAL
THIS DRAWING DESCRIBES A METHOD FOR GENERAL IMPEDANCE TESTING IN THE FREQUENCY RANGE 50 KC TO 50 MC. IT PROVIDES FOR MEASURING THE Q AND RESONANT CAPACITANCE OF AN INDUCTOR; OR FOR MEASURING THE Q AND CAPACITANCE OF A CAPACITOR. THE Q RANGE IS FROM 25 TO 500.
1.0.. SEE 4.1 FOR RESTRICTIONS. AT TEST FREQUENCIES HIGHER THAN 10 MC., OBSERVATIONAL STANDARDS ARE RECOMMENDED.

2. CIRCUIT
THE CIRCUIT SHALL BE CONDUCTIVELY COUPLED RESONANCE TYPE SHOWN SCHEMATICALLY IN FIGURE 1 AND EMBODIED IN THE MODELS 100A AND 160A Q-METER SUPPLIED BY THE BOONTON RADIO CORP., BOONTON, N.J.
2.01 IF THE 60 CYCLE POWER SOURCE VOLTAGE VARIES MORE THAN ± 3 VOLTS AN EXTERNAL VOLTAGE REGULATION DEVICE SHALL BE USED.

2.1 AUXILIARY CAPACITORS

THREE AUXILIARY FIXED TUNING CAPACITORS OF 400, 800, AND 1600 UUF ± 0.5% RESPECTIVELY SHALL BE PROVIDED, FOR EITHER INDIVIDUAL OR COLLECTIVE CONNECTION TO THE EXTERNAL CAPACITANCE TERMINALS OF THE INSTRUMENT. THE Q VALUES MEASURED AT 100 KC, PER KS-4517, SECTION 2, SHALL BE NOT LESS THAN 3000. THE SERIES INDUCTANCE OF THE CONNECTION CIRCUIT SHALL NOT EXCEED .05 MICROHENRIES AND THE RESISTANCE SHALL NOT EXCEED .005 OHM.

2.2 AUXILIARY INDUCTORS
FIVE AUXILIARY SHIELDED INDUCTORS OF .01 H., .001 H., 100,10 AND 1 MICROHENRIES SHALL BE PROVIDED TO PERMIT MEASUREMENT OF RESISTIVE AND CAPACITIVE IMPEDANCES. THE Q VALUES SHALL BE NOT LESS THAN 180 OVER THE TUNING RANGE OF THE 450 UUF, CAPACITOR.

3. REQUIREMENTS
THE EQUIPMENT SHALL MEET THE FOLLOWING REQUIREMENTS:

3.1 TUNING CAPACITOR
THE TOTAL CIRCUIT CAPACITANCE INCLUDING THE LOW RANGE CAPACITOR SET AT ZERO, THE "Q" VOLTMETER, AND THE WIRING SHALL AGREE WITH THE SCALE CALIBRATION TO WITHIN ± (1% + 1 UUF.).

3.2 THERMIONIC "Q" VOLTMETER
THE VOLTAGE SCALE SHALL AGREE WITH A 60 CYCLE VOLTAGE IMPRESSED ACROSS THE CAPACITOR TERMINALS TO WITHIN ± 0.1 VOLT THROUGHOUT ITS RANGE. THE FORM FACTOR OF THE CALIBRATING VOLTAGE SHALL BE WITHIN THE LIMITS 1.10 TO 1.12. THE CATHODE TO GROUND BYPASS CAPACITOR SHALL BE INCREASED TO AT LEAST 8 UF. FOR THIS TEST.

3.3 OSCILLATOR
THE OSCILLATOR FREQUENCY SHALL AGREE WITH THE SCALE VALUES TO WITHIN ± 1% AT ALL FREQUENCIES BETWEEN 50 KC. AND 25 MC. AND TO WITHIN ± 2% BETWEEN 25 MC AND 50 MC.

3.4 THERMOCOUPLE SHIELDING
THE THERMOCOUPLE OF MODEL 100-A Q-METER SHALL BE SHIELDED. MODEL 160-A REQUIRES NO ADDITIONAL SHIELDING.

3.5 STRAY COUPLING
THE PRESENCE OF STRAY COUPLING SHALL BE TESTED BY UNSHIELDED COILS RESONATED BY CONNECTION TO THE CAPACITOR TERMINALS. WITH THE RANGE METER SET AT 500 THE VOLTAGE DEVELOPED IN THE TUNED CIRCUIT AT RESONANCE SHALL NOT EXCEED 0.2 VOLT AS READ ON THE Q-VOLTMETER AT ANY FREQUENCY BELOW 25 MC.

3.5 OVERALL CHECK
THE CIRCUIT CALIBRATION SHALL BE CHECKED PERIODICALLY USING TEST COILS AS PRESCRIBED IN TABLE 1, WHICH HAVE BEEN CALIBRATED BY THE BELL TELEPHONE LABORATORIES NOT LONGER THAN ONE YEAR PREVIOUSLY.

4. OPERATION
THE METHOD OF MEASUREMENT, INCLUDING TEST PROCEDURE AND DETERMINATION OF RESULTS, SHALL BE AS OUTLINED IN THE INSTRUCTION MANUAL FURNISHED WITH THE INSTRUMENT BY THE BOONTON RADIO CORP. COIL SHIELDS IF PRESENT SHALL BE CONNECTED TO THE LOW POTENTIAL TERMINAL UNLESS OTHERWISE SPECIFIED IN THE APPARATUS SPECIFICATION. CAPACITOR SHIELDS SHALL BE GROUNDED UNLESS OTHERWISE SPECIFIED.

4.1 CORRECTIONS
WHENEVER THE RESISTANCE OF THE TEST IMPEDANCE IS LESS THAN 4 OHMS, OR THE TEST FREQUENCY EXCEEDS 4 MEGACYCLES, THE FOLLOWING CORRECTION FACTOR SHALL BE APPLIED:

$$Q_X = Q_M \frac{1 + \frac{.04}{R}}{\sqrt{1 + KM^2}}$$

WHERE Q_X IS THE REACTANCE/RESISTANCE RATIO OF THE TEST IMPEDANCE
Q_M IS THE READING OF THE Q-METER
R IS THE RESISTANCE OF THE TEST IMPEDANCE IN OHMS
M IS THE TEST FREQUENCY IN MEGACYCLES
K IS .0012 FOR MODEL 100A
K IS .0002 FOR MODEL 160-

5. ACCURACY
THE CIRCUIT SHALL BE CHECKED PERIODICALLY IN ACCORDANCE WITH PAR. 3.6 TO WITHIN THE LIMITS OF PAR. 5.1.

THE DEVIATION OF THE SPECIFIED MAXIMUM AND MINIMUM LIMITS FROM THE MEAN VALUE SHALL BE NOT LESS THAN TWICE THE LIMITS OF PAR. 5.1 FOR NORMAL MEASUREMENTS. MEASUREMENTS SPECIFIED BY SUBSTITUTION USING AN OBSERVATIONAL STANDARD MAY BE SPECIFIED TO NOT LESS THAN THE LIMITS OF PAR. 5.2.

5.1 CIRCUIT ACCURACY FOR NORMAL MEASUREMENTS
FOR INDUCTANCE:

$$\pm \left(2.5 + \frac{M}{25} + \frac{5}{L} + \frac{50}{C}\right) \%$$

FOR CAPACITANCE:

$$\pm \left(1 + \frac{5}{L} + \frac{50}{C}\right) \%$$

FOR RESISTANCE OR Q:

$$\pm \left(4 + \frac{Q}{100} + \frac{100}{C} + \frac{4}{R}\right) \%$$

5.2 APPARATUS LIMITS FOR SUBSTITUTION MEASUREMENTS
FOR INDUCTANCE OR CAPACITANCE:

$$\pm \left(1 + \frac{5}{L} + \frac{50}{C}\right) \%$$

FOR RESISTANCE OR Q:

$$\pm \left(3 + \frac{Q}{200} + \frac{50}{C} + \frac{2}{R}\right) \%$$

L IS TEST INDUCTANCE OR RESONANT INDUCTANCE OF TEST CAPACITANCE IN MICROHENRIES.
C IS TEST CAPACITANCE OR RESONANT CAPACITANCE OF TEST INDUCTANCE IN MICROMICROFARADS.
Q IS REACTANCE/RESISTANCE RATIO OF THE TEST IMPEDANCE.
R IS THE RESISTANCE OF THE TEST IMPEDANCE IN OHMS.
M IS THE TEST FREQUENCY IS MEGACYCLES.

5.3
THE ABOVE ACCURACY LIMITS FOR Q OF INDUCTORS APPLY TO MEASUREMENTS MADE WITH THE INDUCTOR CONNECTED TO THE HIGH SIDE OF THE RESONATING CAPACITOR AS IN THE Q METER. THE Q AS DETERMINED BY THIS METHOD WILL BE LESS THAN THE Q AS MEASURED WITH ONE TERMINAL OF THE INDUCTOR GROUNDED, ESPECIALLY WHEN THE RESONATING CAPACITANCE C IS LESS THAN 100 UUF. THE DIFFERENCE MAY BE AS GREAT AS 1000/C %. DEPENDING

UPON THE DISTRIBUTED CAPACITANCE TO GROUND OF THE INDUCTOR.

6. METHOD OF SPECIFYING TESTS

TESTS IN ACCORDANCE WITH THIS DRAWING SHALL BE SPECIFIED SUBSTANTIALLY AS FOLLOWS: -

6.1 NORMAL METHOD

WHEN MEASURED IN ACCORDANCE WITH A-752192 AT A FREQUENCY OF ------KC (OR MC), THE Q VALUE SHALL BE NOT LESS THAN ----- (NOR MORE THAN ---); [AND THE RESONANT CAPACITANCE (OR CAPACITANCE) SHALL BE NOT MORE THAN ----- UUF NOR LESS THAN ----- UUF].

6.2 SUBSTITUTION METHOD

WHEN MEASURED BY SUBSTITUTION IN ACCORDANCE WITH A-752192 AT A FREQUENCY OF -----KC (OR MC) THE INDICATED Q VALUE SHALL BE NOT LOWER THAN ---- % BELOW THE INDICATED Q VALUE OF THE OBSERVATIONAL STANDARD (OR SHALL AGREE WITH THE INDICATED Q OF THE OBSERVATIONAL STANDARD TO WITHIN ±--- % .) AND THE CAPACITANCE SETTING SHALL AGREE WITH THE CAPACITANCE SETTING FOR THE OBSERVATIONAL STANDARD TO WITHIN ± -----UUF (OR ±----- %).

*(SHIELDING IS SHOWN ON ESO-627515)

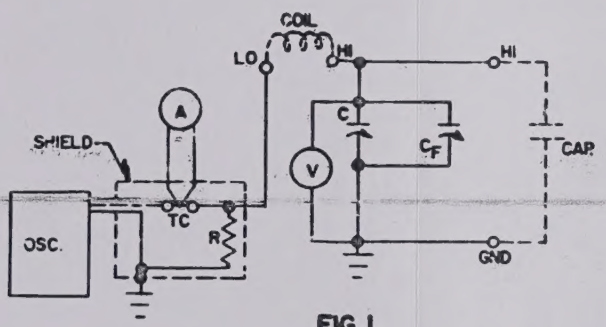


FIG. 1

A= THERMOAMMETER 0-0.5 AMPERE.
R= .01 OHM COUPLING RESISTOR
V= V.T. VOLTMETER 0-5 VOLTS
C= 40-450 UUF TUNING CAPACITOR
C_F= PLUS AND MINUS 2 UUF TUNING CAPACITOR.

TABLE I

TEST FREQUENCY MC.				
C → UUF / TEST L↓ MICROHENRY	40	200	400	2500
0.2	50.	25.	-	-
1	25.	-	8.	3.
10	8.	-	2.5	1.
100	2.5	-	.8	.3
1000	.8	-	.25	.1
10000	-	.11	.08	-

NOTE CAPACITANCE VALUES ARE APPROXIMATE ONLY.

A-752192

REDRAWN 6-15-66

304A INDR	A-753047
304B INDR	
304C INDR	
304D INDR	
304E INDR	
304F INDR	
304G INDR	
293B INDR	A-752202
293A INDR	A-752203
AT 3 INDR	A-752212

Q- METER TEST CIRCUIT

SCALE NONE

WESTERN ELECTRIC CO. INC ENGINEER OF MANUFACTURE

BELL TELEPHONE LABORATORIES INC

DIMENSIONS UP TO AND INCLUDING 72 INCHES EXPRESSED IN INCHES NON LIMITED DIMENSIONS OTHER THAN SIZE OF RAW MATERIAL SHALL BE HELD WITHIN FRACTIONAL DECIMAL

SIZE 4S

CDS A-752192

MP MASTER
MA24747